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Review of PIM (Pipeline Insertion Method) Technology

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The U.S. Army Construction Engineering Research Laboratory (USACERL) conducted the first demonstration of PIM (Pipeline Insertion Method, formerly Pipe Insertion Machine) technology for sewer rehabilitation in the United States in 1987, complete with a battery of physical testing for vibration and soil deformation. The technology, first developed for gas main replacement, uses an impact mole to burst the existing pipe outward into the surrounding soil and replace it at the same rate with HDPE (High Density Polyethylene). PIM is the foremost trenchless technology which can replace existing pipe with equal or larger diameter pipe. The technology is applicable to sewer, water, and gas mains and can be cost-competitive with open trench techniques in specialized circumstances, such as areas with high surface restoration costs: under paved areas, through environmentally sensitive areas, etc. A body of knowledge has developed during the past two years as the number of users has increased. This paper will summarize the existing state-of-the-art of the technology with wastewater collection systems including information on applicability, economics, advantages and disadvantages, and lessons-learned.

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The U.S. Army Construction Engineering Research Laboratory (USACERL) conducted the first demonstration of PIM (Pipeline Insertion Method, formerly Pipe Insertion Machine) technology for sewer rehabilitation in the United States in 1987, complete with a battery of physical testing for vibration and soil deformation. The technology, first developed for gas main replacement, uses an impact mole to burst the existing pipe outward into the surrounding soil and replace it at the same rate with HDPE (High Density Polyethylene). PIM is the foremost trenchless technology which can replace existing pipe with equal or larger diameter pipe. The technology is applicable to sewer, water, and gas mains and can be cost-competitive with open trench techniques in specialized circumstances, such as areas with high surface restoration costs: under paved areas, through environmentally sensitive areas, etc. A body of knowledge has developed during the past two years as the number of users has increased. This paper will summarize the existing state-of-the-art of the technology with wastewater collection systems including information on applicability, economics, advantages and disadvantages, and lessons-learned.

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FOREWORD

This is a reprint of a paper that appeared in *Pipeline Design and Installation*, Proceedings of the International Conference, sponsored by the American Planning Committee of the *Pipeline Division* of the American Society of Civil Engineers, March 25-27, 1990. The paper was based on research being done for the U.S. Army Engineering and Housing Support Center (USAEHSC) as part of the Facilities Engineering Applications Program (FEAP), Work Unit K89 "Rehabilitation of Sewage Pipes." Work was performed by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (USACERL).

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The USACERL principal investigator was Richard J. Scholze. Assistance was provided by Stephen W. Maloney, Dr. Edgar D. Smith, and Dr. Prakash M. Temkar. Dr. Edward W. Novak is Acting Chief of USACERL-EN.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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Introduction

An "INFRASTRUCTURE CRISIS," cry newspaper and magazine headlines, has hit this country for roads, bridges, sewers, waterlines, treatment plants, and utilities. Wastewater collection systems, while being the largest capital investment by a wastewater utility, traditionally receive little attention until a problem arises; because the components are out of sight, they're out of mind. Many communities face serious problems with a large percentage of sewers being collapsed or in need of urgent attention. Others experience hydraulic overload due to new development or inflow/infiltration. Repair, renovation, and replacement are the major options for rehabilitation of sewers. On-line replacement, i.e. "no-dig" or trenchless technologies, have recently been receiving increased attention as innovative, cost-effective rehabilitation techniques are sought. One technology which is receiving attention is the pipeline insertion method (PIM) which can replace existing sewers with a larger size pipe. This technology can increase hydraulic capacity while supplying new lines. The proprietary technique is protected with a method patent and marketed in the U.S. by PIM Corporation of Piscataway, NJ.

Technology

The PIM concept and technology were developed in Great Britain, following an original proposal for experimental research in the U.S.S.R. as a method for replacement of cast iron gas mains. Since then the technology has seen additional use for sewer and water lines and, although primarily European in usage, the process is becoming more widely used in North America. In addition to the applications discussed in this paper, the technology has been used in suburban Washington, D.C., Long Island (New York), and Regina and Edmonton (Canada).

"Impact mole" or "pipe bursting" technology involves installing larger pipes into the place of existing older lines. The technology consists of fragmenting the pipe in place and forcing it into the surrounding soil with an impact mole. A new pipe of high density polyethylene is then pushed into the existing sewage collection route manhole to manhole. Thus, it can be installed without disturbing the surface. PIM has the capability to not only replace size for size but to upsize existing pipe, up to 50 percent greater cross sectional area. The process requires excavation for insertion pits at every other manhole and a reception pit for removal of the mole. In addition, smaller excavation pits are required for every functioning lateral connection.

The bursting of the pipe material is accomplished by the use of pneumatic (Figure 1) or hydraulic bursters. In the hydraulic system, the mole is towed by a winch, while the new pipe is towed behind the mole. In the pneumatic system for replacing pressure pipe, the mole is guided by a winch and the pipe is tensioned and towed behind the mole. In the pneumatic system for nonpressure pipe, the mole is guided by the winch, and the new pipe is hydraulically jacked behind the mole, enabling it to achieve greater distances (Figure 2).

Figure 1. Impact Mole Just Before Connection to HDPE Pipe, Showing Airline Inside HDPE Pipe.

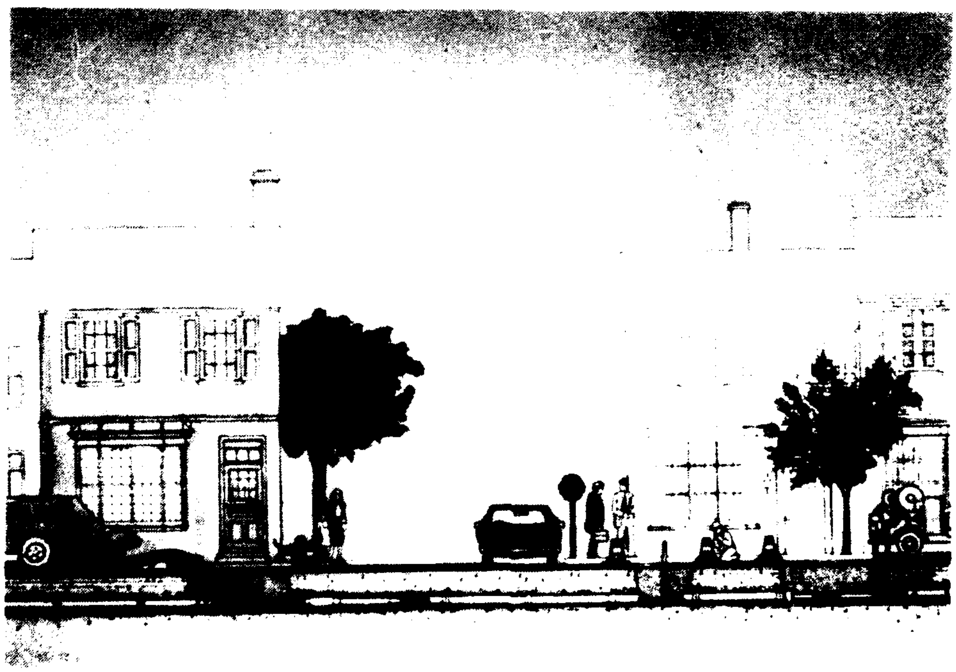

Figure 2. Diagram of Pipe Insertion Methodology for On-line Sewer Replacement.

PIPELINE INSERTION METHOD

Distinct variants have evolved: a pressure pipe replacement system and a non-pressure pipe replacement system. These are differentiated by the characteristics of the pipes themselves. Pressure pipes (e.g. gas) tend to be of smaller diameter and laid at a more shallow depth than the larger diameter gravity systems. Initial development of the system concentrated on small-diameter gas mains. The gas mains were originally constructed of cast iron, so a PVC-liner pipe is used as a precaution against damage to the HDPE by metal fragments. The PVC liner is first pulled into place behind the impact mole as it breaks up the existing pipe. Then a HDPE pipe is slid into place inside the protective PVC liner. Non-pressure pipes found in sewer systems are made of more brittle materials such as vitrified clay, which pose less of a threat to the HDPE pipe, thus no PVC liner is used. These pipes also tend to be much larger, making it difficult for the impact mole to both break up the existing pipe and pull in the new pipe. Therefore, a 25 ton pushing machine, placed in the insertion pit, is used to force the new HDPE pipe into the cavity created by the impact mole. This new pipe is connected to the impact mole by a collar which allows the new pipe a limited degree of independent movement.

The pneumatic equipment allows replacement of pipelines from 2 inch to 20 inch, although most applications have been at the lower end of this range (6 inch - 8 inch). However, it has been used to expand pipes from 10 to 16 inches in diameter. Using the hydraulic option, 6 inch and 8 inch mains have been replaced.

The hydraulically-powered burster differs from the pneumatic burster in that the bursting action comes from sequentially expanding and retracting the top section of the burster as it is pulled through the existing pipe. The forward motion is provided by a simple winch in the receiving pit and the replacement pipe is connected directly to the burster. The expanding section of the burster is powered by an external hydraulic power unit with supply and return hoses running through the replacement pipe.

The high frequency bursting action on dry clay soil in a California application (Jacobs et al., 1988) causes the existing pipe and the surrounding soil to fracture (as opposed to the pneumatic burster which compacts the soil in all directions). The fractured soil collapses on the replacement pipe causing significant friction. The increased friction and limited power available from the winch combine to limit runs to about 250 feet.

The advantage of the hydraulic burster is its short length. With the hydraulic burster's approximate 3 foot overall length, the excavations for the launch and retrieval pits are much smaller than required for the pneumatic burster. The shorter length allows it to negotiate shorter radius curves. The hydraulic option also is reported to work better in wet environments. The annular space around the replacement pipe is smaller and it appears to be filled with soil fractured by the action of the burster. The disadvantages are the shorter runs and slower speed (1 fpm).

PIM can be used on any brittle, fracturable pipe. Successful use has been with cast iron, asbestos cement, and clay. The process can also be used with some plastics such as ABS and PVC. Improvements such as blades on the front of the mole assist in penetration of plastics. It is not useful for replacing ductile materials such as steel or ductile iron or for plastics such as HDPE, which can stretch.

PIPELINE DESIGN AND INSTALLATION

PIM Application For Sewers

Sewer replacement requires the following basic installation technique. A site survey is required, which includes locating other underground facilities, and an initial closed-circuit television camera survey (accurate within 2 inches), which pinpoints the locations of lateral connections and of any structural defects. Appraisal of redundant laterals is performed; roots and other intrusions are removed as the line is cleaned. Manholes are chosen for both flow diversion and as access and exit points. Section lengths are maximized, minimizing excavation of pits and laterals. Effective flow diversion is planned and executed. Efficient operation of the pipe bursting equipment is conducted. (Normal operation is one day's conduct of pipe bursting with appropriate preparation and follow-on service to minimize customer inconvenience.) Reconnection of laterals on completion and reinstatement of manholes and excavations and repaving complete the tasks.

The pipeline can be assembled in continuous lengths of up to 400 feet at the roadside. These connections are made by the butt fusion method. The faces of the sections to be joined are heated, then forced together under pressure. When properly fused, the resulting seal is stronger than the pipe itself. The same method is used to make service connections.

Benefits Of Technology

The cost of sewer construction is often dictated by the cost of surface restoration. The actual pipe cost can be 20 percent or less of the overall construction cost. The use of pipe insertion rather than an open trench will allow savings in areas where surface restoration or trench construction is especially costly such as easements, sensitive or high visual impact environmental areas like golf courses or parks, and areas with surface traffic. A major benefit, difficult to measure in terms of dollars, is the avoidance of closed areas such as roads and parking lots. Careful planning of insertion pit locations can avoid all disruptions in surface activity associated with open trench methods. Additional advantages are listed in Table 1.

Fort Belvoir Application

At Fort Belvoir, Virginia, the U.S. Army Construction Engineering Research Laboratory performed the first U.S. demonstration of the technology for sewer upgrade. Two hundred and forty feet of 8-inch main was placed in the path of an existing 6-in. main which traveled between two manholes, under two parking lots, one well-traveled street, a retaining wall, and a fence. Passage of a pneumatic mole destroyed the old pipe and made a passage for the new high density polyethylene pipe. Traffic was maintained and the wall and fence were not affected.

Table 1

Advantages of PIM Technology

Trenchless
Uses existing pipe for subsurface lane
Upsizing capabilities
Capital improvement, not maintenance
Minimizes traffic inconvenience
Minimizes public inconvenience
Cost savings in paving excavation and replacement costs
Useful in areas with high surface traffic
Useful in easements, limited work surface
Good public relations
Possible time savings
Engineering costs are lower than "open cut"

The primary disadvantage is the cost. It is an expensive option, therefore, it must be applied appropriately. There is also the possibility of surface disturbances in dense soils.

During the course of the demonstration at Fort Belvoir, Virginia, a series of tests were performed during construction to determine the effect of the mole on adjacent utilities. Standard procedure in the PIM technique is to expose areas where pipes cross the path of the mole and remove the dirt between the pipe being replaced and the crossing pipe. This is a safety precaution; however, engineers often have incomplete plans of buried utilities. Tests were designed to measure potential effects on pipes which were not known and exposed to relieve stress. An experiment was set up with instrumented pipe in place perpendicular to mole direction and 16 inches above it. Three rods were sunk into holes at various depths above the pipe, a pipe (4-inch ductile iron) with strain gages attached was installed 16 inches above the pipe. In addition, geophones were placed on the surface directly over the pipe being replaced, and at least 9 feet from the centerline, to measure vibrations induced by the impact mole. After construction, measurements of deflection of the newly installed pipe were taken to determine if it maintained its roundness.

The results of these tests are detailed elsewhere (Briassoulis et al., 1989) and will only be summarized here. Stress induced on the adjacent pipe produced only small strains, with the maximum strain above the impact mole's path being 200. Figure 3 shows the longitudinal strain distribution along the crown line of the instrumented pipe as the mole was passing by. The mole was beneath the instrumented pipe. The results were found to be not significant. Maximum strain was developed at the crown of the instrumented pipe just above the sewer pipe. This is an example of classic strain distribution for a beam on an elastic foundation.

Soil displacements measured at different elevations above the sewer pipe as the mole was passing by are shown in Figure 4. The maximum soil displacement was 0.60

inch at 16 inches above the sewer pipe. This compares to an increase of pipe radius of 1 inch and an even larger expansion of the surrounding soil by the 10-inch diameter mole. Soil deformation in this test was essentially plastic.

Deformation of the new pipe may also pose a problem. Deformation of the new polyethylene pipe is shown in Figure 5 with a maximum deformation of 2.5 percent change of pipe diameter. A second test conducted 6 months later showed the magnitude of deflection had increased to 4.5 percent, which is almost at the recommended acceptable deformation of 5 percent (8-inch SDR 17 pipe).

A subsequent test of deformation after one year indicated that the vertical deflection increased a small amount, whereas the horizontal deflection decreased slightly. The decrease in horizontal deflection may be due to the soil recovering and sealing completely around the pipe. The net result is that deflection is remaining less than 5 percent of the original diameter.

Vibrations were also noted as a potential problem. Vibrations directly over the pipe were found to be significant. The maximum vertical peak particle velocity reached 0.54 in./s when the mole was beneath the array of geophones (Briassoulis et al. 1989), but damped out quickly (0.06 in./s) at the 9-foot distance from the mole path centerline.

The results from U.S. Army and British tests were compared (Briassoulis et al, 1989) and were shown to be comparable to vibrations induced by jackhammers. Figure 6 shows a comparison between maximum PPV (Peak Particle Velocity) due to the impact mole and due to jack hammers and trucks. Thus, care should be exercised in locating and protecting (e.g., by excavating and removing the soil between the mole and the critical object) utilities and structures sensitive to vibration.

The conclusion is that, with regard to vibration effects, the PIM technique should not be considered as more damaging compared to other alternatives such as excavation using jack hammers, or to usual sources of vibration like trucks, except for buried pipes and archeological objects located close to the operating mole. Vibrations appear to dampen out quickly.

At Fort Belvoir, the use of the mole technology resulted in minimal surface disruptions. The retaining wall and fence were not affected by the construction and traffic was maintained at all times.

Economics

The Central Contra Costa Sanitary District (CCCSD) is one of the leading users of PIM technology in the U.S. with demonstrations of several thousand linear feet during 1987-1989 at a number of sites and information from their experience (Decker and Larson, 1988; Jacobs et al., 1988) has expanded the available limited data base.

Cost figures from the CCCSD (Decker and Larson, 1988; Jacobs et al., 1988) experience for 8 different runs ranged from \$51 to \$83/ft in 1987 and from \$69 to \$86/ft during 1988 as approximately 7000 feet of sewer was upsized from 6 to 7.5 inch

diameter. Runs were made through a variety of terrains and soils, predominantly adobe clays which are very dense and difficult to compact. The runs were all in easements, often extensively vegetated and steep. Overall savings using the tecnology were estimated at 6, 11, 15, 16, 28, 28, 44, and -42 percent for each of the 8 runs. It must be noted that the negative savings value was for a run made across a golf course.

CCCSD continued the use of PIM technology during 1989 with their most challenging applications to date (Kurasaki, 1989). For example, one run was at a depth of 20 feet, another within 12 feet of a swimming pool, a third ran 4 feet from a home, a run under telephone ducts in pea gravel, through a schoolyard with disruptions, and a 700 foot run on a steep hillside. Contract cost figures ranged from $82 to $99/linear foot with approximately 3300 feet of 6 inch main replaced with 8 inch main at an average cost of $94/foot. Overall costs to the sanitary district were approximately $102/foot which included their construction management time, field time, fence removal and repair, and similar contingencies. They (Kurasaki, 1989) again found the method to be more cost-effective than open-trench operations for the selected sites.

Using the PIM method, replacing 600 feet of cast iron requires a little more than 175 square feet of repaving, as opposed to nearly 1400 square feet of repaving required by direct burial. That's due to the two major excavations and the small access pits are dug to expose each service connection to allow customers to be tied into the new main.

Lessons-Learned

Lessons-learned from CCSD (Jacobs et al., 1988) experience have established the following minimum specifications for future pipe bursting projects:

- Use of fusion welded saddles for service lateral reconnection
- Removal of all internal butt fusion weld beads
- Repair or correction of all major low spots in existing pipe prior to pipe bursting operation
- Minimum cover of 3 feet in easements and 5 feet in streets
- Final inspection to include low pressure air test, deflection test with 95 percent mandrel, and CCTV inspection
- One year warranty in installation and materials with deflection test at end of warranty period

They also noted short sags (less than 10 feet) appeared to be corrected by the longer length of the pneumatic burster.

PIPELINE DESIGN AND INSTALLATION

Jacobs et al., (1988) conclude that pipe bursting is cost effective for gravity sewer replacement in easement situations when compared to conventional open-cut methods when the following factors are considered:

- Difficulty of access
- Depth of pipe
- Width of easements and encroachments
- Impact on local residents/commercial activities
- Restoration of surface improvements
- Reduced risk due to unknown conditions
- Improved safety to workers and local residents

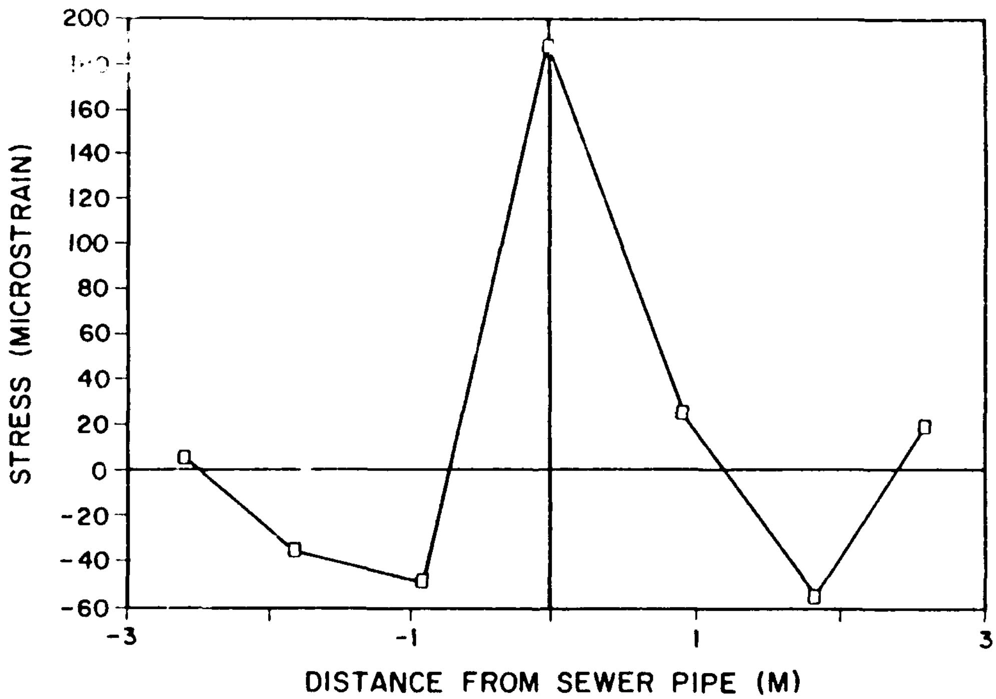

Figure 3. Longitudinal Strain Distribution Along the Crown Line of the Instrumented Pipe When Mole Was Passing By (Mole Beneath Instrumented Pipe).

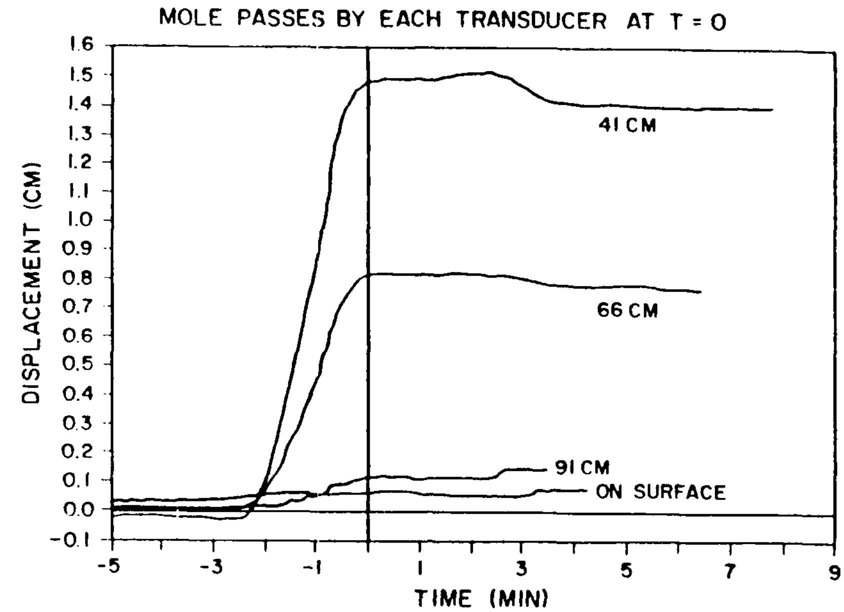

Figure 4. Soil Displacement at Different Depths Above Sewer Pipe as Mole Was Passing By. (Results are normalized so that time zero corresponds to the time when mole was beneath the displacement transducer).

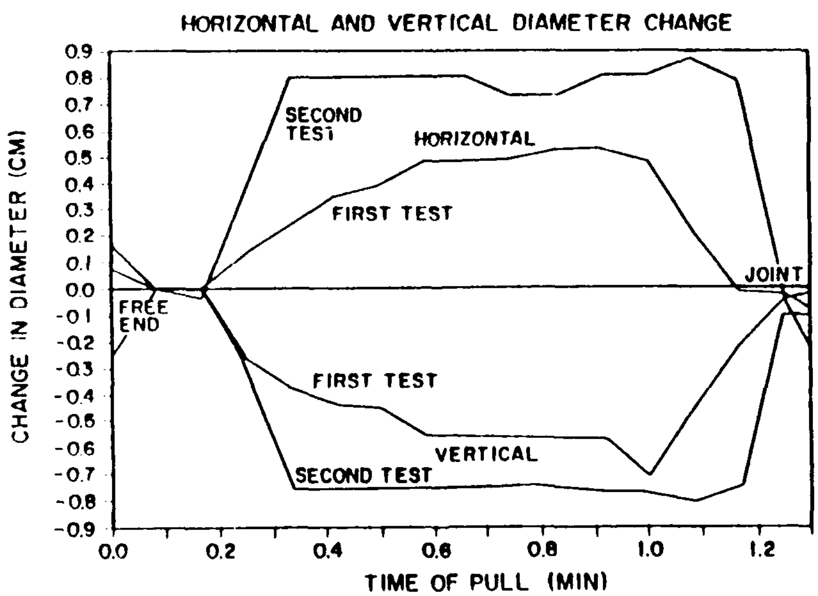

Figure 5. Deformation of Inserted Polyethylene Pipe After Installation (Deformation is Elliptical).

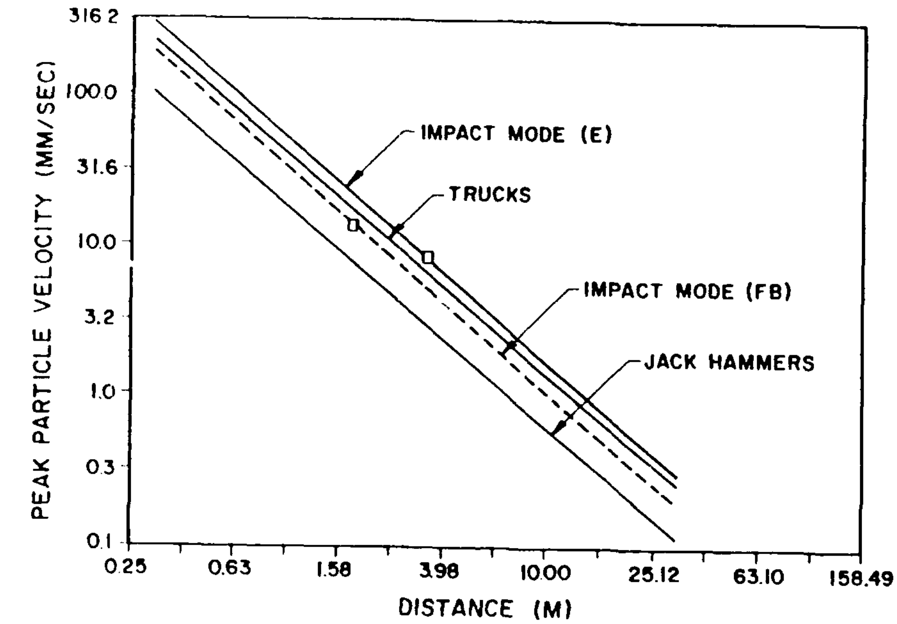

Figure 6. Comparison of Attenuation Curves for Jack Hammer and Trucks and PIM Technique Tests. E = England, FB = Fort Belvoir.

Summary

PIM technology is gaining acceptance in the U.S. as a method for rehabilitating and upsizing sewer lines. Experience is being gained for optimal application of the technology and its effect on the surrounding soils.

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